Composite Adaptive Control of Boost Converter in Presence of Bounded Disturbances

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***Abstract*—In this paper, composite adaptive control is applied to improve the controller efficiency of the DC/DC boost converter. The proposed composite controller updates the controller parameter using the tracking error with a reference model and also using prediction error after estimation of parameters of the boost converter. The controller can handle the state-dependent matched uncertainties and the bounded disturbances. Controller stability is shown through Lyapunov analysis. The complete control architecture is applied and validated with the simulation of a boost converter, where the main aim of the controller is to track the desired voltage. The controller's performance is checked for variation in sudden load and input voltage.**

***Index Terms*—Composite Adaptive Controller, Boost Converter, Simple Adaptive Control**

I. Introduction

Renewable energy sources such as solar arrays are emerging as a promising source of green, clean and reliable energy, and an efficient DC/DC boost conversion is essential to generate highly regulated DC voltage. In the case of renewable energy sources, the output dc voltage is low, and DC/DC boost converter is required to step up the voltage from supply to load. Boost converter systems are subjected to high uncertainties due to changes in circuit parameters, load change, disturbances in input voltage, and unmodelled dynamics [1]. Additionally, the dynamics of the boost converter are highly non-linear and generally associated with non-minimum phase zeros [2]. In literature, the controller for boost converter is developed using a non-cascaded approach where the controller for voltage and current is designed together [3], [4]; and in the cascaded approach controller for current and voltage is designed separately using inner-loop outer-loop approach [5], [6]. Various advanced controller has been reported in literature for boost converter system such as sliding-mode control [7], [8], Robust control [9], [10], adaptive control [11], [12], and machine learning [13].

A single fixed controller will not be able to provide the desired transient performance while ensuring stability at all operating points of the plant. Considering the uncertainty associated with the boost converter, an adaptive control will be a suitable candidate for controller design as it can adapt the control parameters based on the different conditions. Controller for boost converter using the Simple Adaptive Control (SAC) using output feedback is reported in [2], [12]. In SAC formulation, the non-minimum phase zeros of the plant are handled using the augmentation of a parallel feedforward compensator and, therefore, suitable for boost converter application. An adaptive-PI controller is proposed for the regulation of output voltage of quadratic boost converter [3]. In [14], an adaptive controller is used to reduce the harmonic disturbances in the input voltage.
The existing adaptive control approaches for boost converters are based on the direct adaptive control, where control law is generated using the error between the plant and the references model. Another approach in adaptive control is based on indirect adaptive control, where control law is developed after the estimation of plant parameters. The estimation of plant parameters improves plant performance. A combination of direct and indirect adaptive control can be used to further improve the efficiency of the boost converter. Composite adaptive control architecture like CMRAC [15], PMRAC [16], AMRC [17] are reported in literature using the state information.

In this paper, we have applied the composite adaptive control framework for the controller of the boost converter. Composite adaptive control using the output feedback for the plant with state-dependent matched uncertainties was initially proposed in [18]. Here, the controller structure is developed using the SAC [19]–[21]; however, the plant parameters are updated using the tracking error and prediction error. In this paper, we have extended the framework of composite adaptive control with the incorporation of the state-dependent bounded disturbances in the plant dynamics. The stability analysis of the proposed controller is performed using the Lyapunov function. The controller architecture of the boost converter is designed using the composite adaptive control framework, and the controller is validated using the simulation. The robustness of the controller is verified with variations in sudden load and input voltage. The main contribution of the paper lies in the following aspects.

- Extension of composite adaptive controller framework with time-varying bounded disturbances.

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- Design and validation of composite adaptive control framework for a DC/DC booster converter.

The rest of the paper is organized as follows: Section II shows the linearized model of a typical boost converter. The problem formulation of the composite adaptive control framework is described in Section III. The composite control law is described in Section IV. The stability of the proposed controller is derived in Section V. Section VI shows the simulation results for the proposed controller.

II. Boost Converter

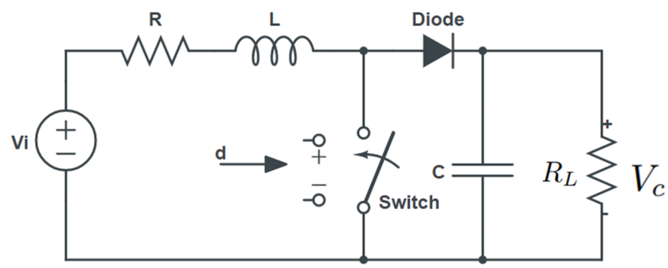


Fig. 1: Boost converter

A DC/DC boost converter, as shown in Fig. 1 can be modeled using the average switching method is as follows,

$$\frac{di_L}{dt} = -\frac{R}{L}i_L - \frac{1}{L}(1-d)v_c + \frac{1}{L}V_i \tag{1}$$

$$\frac{dv_c}{dt} = \frac{1}{C}(1-d)i_L - \frac{1}{R_L C}v_c \tag{2}$$

where, plant states are inductor current (i_L) and output voltage (v_c), and plant control input is duty ratio (d). V_i is input voltage, R is parasitic resistance of inductor, L is inductance, C is capacitance, and R_L is load resistance. Considering the non-zero value of R, the linearized model of the boost converter with system state x and control input u can be written as,

$$\dot{x} = \begin{bmatrix} -\frac{R}{L} & -\frac{1-D}{L} \\ \frac{1-D}{C} & -\frac{1}{R_L C} \end{bmatrix} x + \begin{bmatrix} \frac{V_c}{L} \\ -\frac{I}{C} \end{bmatrix} u \tag{3}$$

where, $x = [i_L \quad v_c]^T$, $u = d$, V_c is the desired output voltage, I and D are equilibrium values of i_L and d. Here, it is considered that both states are measurable. Therefore,

$$y = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x \tag{4}$$

The equilibrium values of the D and I is calculated as follows,

$$D = 1 - \frac{1}{2}\left(\frac{V_i}{V_c} + \sqrt{\left(\frac{V_i}{V_c}\right)^2 - 4\left(\frac{R}{R_L}\right)}\right) \tag{5}$$

$$I = \frac{V_c}{R_L(1-D)} \tag{6}$$

The main objective is to design a controller which can handle the parameter uncertainties and provide robustness against the perturbation in output voltage in presence of bounded disturbances.

III. Problem formulation

Consider a multi-input multi-output dynamical systems with unstructured matched state-dependent uncertainty and bounded noise components as

$$\dot{x}_p = A_p x_p + B_p\big(u_p + f(x_p)\big) + \zeta(t) \tag{7}$$

$$y_p = C_p x_p \tag{8}$$

where, $x_p \in \mathbb{R}^{n_p}$, $u_p \in \mathbb{R}^m$, $y_p \in \mathbb{R}^p$, $\zeta(t) \in \mathbb{R}^{n_p}$ are system state vector, control inputs, outputs, and uniformly noise components. $\zeta(t)$ is bounded time varying unknown disturbance with known upper bound, i.e, $\zeta(t) \leq \zeta_{\text{max}}$. $f(x_p)$ denotes unstructured matched state-dependent uncertainty and it is expressed as $f(x_p) = \Theta^T\Phi(x_p)$, where Θ are the unknown constant "true" parameters and $\Phi(x_p)$ is known regression vector. The components of $\Phi(x_p)$ are assumed to be locally Lipschitz continous in x_p. A_p, B_p, C_p are known system matrices, $(A_p,\ B_p)$ is controllable and $(A_p,\ C_p)$ is observable. It is assumed that plant output (p) is greater than the number of control inputs(m), and rank (C_pB_p)=m The control objective is to design u_p such that the plant tracking outputs track the reference command while tracking the output of a reference model. The plant tracking outputs are defined as,

$$y_t = C_t x_p \tag{9}$$

where y_t are the output variables which need to track the reference command. We assume the dimension of plant tracking output (y_t) is the same as the number of control inputs (m). The reference model is driven by the desired command for the plant, and it is designed as bounded input bounded out stable plant with responses according to the expected plant responses. The reference model is considered as,

$$\dot{x}_m = A_m x_m + B_m u_m \tag{10}$$

$$y_m = C_m x_m \tag{11}$$

where, $x_m \in \mathbb{R}^{n_m}$, $u_m \in \mathbb{R}^{m_m}$, $y_m \in \mathbb{R}^m$ are the states, control inputs and outputs of the reference model respectively. The matrix A_m is considered as Hurwitz matrix. As the plant tracking output has to track the reference model output, the dimension of (y_m) and (y_t) is same.

IV. Control law

The control law is generated using the output tracking error with the reference model and prediction error using an observer. The output tracking error is defined as the difference between the plant tracking output (y_t) and the reference model output (y_m).

$$e_y = y_m - y_t \tag{12}$$

The prediction error is defined as the plant tracking output and corresponding observer states.

$$e_{\text{pre}} = C_t x_p - C_t\hat{x_p} \tag{13}$$

where, $\hat{x}_p \in \mathbb{R}^{n_p}$ is the state of the observer dynamics. Observer dynamics is considered as,

$$\dot{\hat{x}}_p = A_p\hat{x}_p + B_p\big(u_p + \hat{\Theta}^T\Phi(x_p)\big) + m_v(y_p - \hat{y}_p) \quad (14)$$

$$\hat{y}_p = C_p\hat{x}_p \quad (15)$$

where, $\hat{\Theta}^T$ is predicted unknown parameter matrix, m_v is observer gain matrix.
The controller law is defined as,

$$u_p = K(t)r \quad (16)$$

where, $K(t) = [K_e(t), K_x(t), K_u(t), K_m(t)]$ and

$$r = [e_y, x_m, u_m, \Phi(x_p)]' \quad (17)$$

$$K_e(t) = K_{pe}(t) + K_{Ie}(t) \quad (18)$$

$$K_{pe}(t) = e_y e_y^T \Gamma_{pe} \quad (19)$$

$$\dot{K}_{Ie}(t) = \text{Proj}(K_{Ie}, e_y e_y^T \Gamma_{Ie} - \sigma K_{Ie}) \quad (20)$$

$$K_x(t) = K_{px}(t) + K_{Ix}(t) \quad (21)$$

$$K_{px}(t) = e_y x_m^T \Gamma_{px} \quad (22)$$

$$\dot{K}_{Ix}(t) = \text{Proj}(K_{Ix}, e_y x_m^T \Gamma_{Ix}) \quad (23)$$

$$K_u(t) = K_{pu}(t) + K_{Iu}(t) \quad (24)$$

$$K_{pu}(t) = e_y u_m^T \Gamma_{pu} \quad (25)$$

$$\dot{K}_{Iu}(t) = \text{Proj}(K_{Iu}, e_y u_m^T \Gamma_{Iu}) \quad (26)$$

$$\dot{K}_m(t) = \text{Proj}\big(K_m, e_{pre}\Phi(x_p)^T\Gamma_m\big) \quad (27)$$

where Γ_{Ie}, Γ_{Ix}, Γ_{Iu} and Γ_m are constant positive semi-definite weight matrix, and Γ_{px}, Γ_{Ix}, and Γ_{pu} is constant positive definite matrix. Proj is the standard projection operator as defned in [22].

V. Stability proof

In this section, stability analysis of the plant is performed. It is assumed that when the plant output tracks the reference model output perfectly, plant state and control trajectories follow the ideal plant and ideal control trajectory.

$$\dot{x}_p^* = A_p x_p^* + B_p\big(u_p^* + \Theta^T\Phi(x_p^*)\big) \quad (28)$$

where, x_p^* are states of the ideal plant with ideal control u_p^*. Ideal control is defined as

$$u_p^* = \tilde{K_x}x_m + \tilde{K_u}u_m + \tilde{K_m}\Phi(x_p^*). \quad (29)$$

So, in the case of perfect tracking,

$$y_p^* = C_t x_p^* = y_m = C_m x_m \quad (30)$$

Therefore, the error between the plant state and the ideal state is defined as,

$$e_x = x_p^* - x_p. \quad (31)$$

From (7), and (28); error dynamics can be written as

$$\dot{e_x} = A_p x_p^* + B_p\big(u_p^* + \Theta^T\Phi(x_p^*)\big) - A_p x_p - B_p\big(u_p + \Theta^T\Phi(x_p)\big) - \zeta(t) \quad (32)$$

Using the values of plant control input (u_p) and ideal control u_p^*,

$$\dot{e_x} = A_p x_p^* + B_p\big(\tilde{K_x}x_m + \tilde{K_u}u_m + \tilde{K_m}\Phi(x_p^*) + \Theta^T\Phi(x_p^*)\big) - A_p x_p - B_p\big(K(t)r + \Theta^T\Phi(x_p)\big) - \zeta(t) \quad (33)$$

Therefore,

$$\dot{e_x} = A_p x_p^* + B_p\big(\tilde{K_x}x_m + \tilde{K_u}u_m + \tilde{K_m}\Phi(x_p^*) + \Theta^T\Phi(x_p^*)\big) - A_p x_p - B_p\big(K_e(t)e_y + K_x(t)x_m + K_u(t)u_m + K_m(t)\Phi(x_p) + \Theta^T\Phi(x_p)\big) - \zeta(t) \quad (34)$$

Equivalently,

$$\dot{e_x} = A_p(x_p^* - x_p) + B_p\big(\tilde{K_x} - K_x(t)\big)x_m + B_p\big(\tilde{K_u} - K_u(t)\big)u_m + B_p\big(\tilde{K_m}\Phi(x_p^*) - K_m(t)\Phi(x_p)\big) + B_p\Theta^T\big(\Phi(x_p^*) - \Phi(x_p)\big) - B_pK_e(t)(C_m x_m - C_t x_p) - \zeta(t) \quad (35)$$

Using, (30) and (31),

$$\dot{e_x} = A_p e_x - B_pK_e(t)\big(C_t x_p^* - C_t x_p\big) + B_p\big(\tilde{K_x} - K_x(t)\big)x_m + B_p\big(\tilde{K_u} - K_u(t)\big)u_m + B_p\big(\tilde{K_m}\Phi(x_p^*) - K_m(t)\Phi(x_p)\big) + B_p\Theta^T\big(\Phi(x_p^*) - \Phi(x_p)\big) - \zeta(t) \quad (36)$$

Adding and subtracting $B_p\tilde{K}_e e_y$, we get

$$\dot{e_x} = A_p e_x - B_pK_e(t)C_t e_x + B_p\tilde{K}_e e_y - B_p\tilde{K}_e e_y + B_p\big(\tilde{K_x} - K_x(t)\big)x_m + B_p\big(\tilde{K_u} - K_u(t)\big)u_m + B_p\big(\tilde{K_m}\Phi(x_p^*) - K_m(t)\Phi(x_p)\big) + B_p\Theta^T\big(\Phi(x_p^*) - \Phi(x_p)\big) - \zeta(t) \quad (37)$$

Hence,

$$\dot{e_x} = (A_p - B_p\tilde{K}_e C_t)e_x + B_p(\tilde{K_e} - K_e)e_y + B_p\big(\tilde{K_x} - K_x(t)\big)x_m + B_p\big(\tilde{K_u} - K_u(t)\big)u_m + B_p\big(\tilde{K_m}\Phi(x_p^*) - K_m(t)\Phi(x_p)\big) + B_p\Theta^T\big(\Phi(x_p^*) - \Phi(x_p)\big) - \zeta(t) \quad (38)$$

We consider the following Lyapunov function candidate,

$$V(t) = e_x^T P e_x + tr[\big(K_{Ie}(t) - \tilde{K_e}\big)\Gamma_{Ie}^{-1}\big(K_{Ie}(t) - \tilde{K_e}\big)^T] + tr[\big(K_{Ix}(t) - \tilde{K_x}\big)\Gamma_{Ix}^{-1}\big(K_{Ix}(t) - \tilde{K_x}\big)^T] + tr[\big(K_{Iu}(t) - \tilde{K_u}\big)\Gamma_{Iu}^{-1}\big(K_{Iu}(t) - \tilde{K_u}\big)^T] + tr[\big(K_m(t) - \tilde{K_m}\big)\Gamma_m^{-1}\big(K_m(t) - \tilde{K_m}\big)^T] \quad (39)$$

where, $P = P^T > 0$ is the solution of the following equations

$$P(A_p - B_p\tilde{K}_e C_t) + (A_p - B_p\tilde{K}_e C_t)^T P = -Q \quad (40)$$

$$PB_p = C_t^T\ . \quad (41)$$

Here, Q is a positive definite symmetric matrix. A minimum phase plant with C_tB_p positive definite symmetric satisfies the condition in Eqn. 40 and Eqn. 41, and the plant is called "almost strictly passive (ASP) and corresponding transfer function as "almost strictly positive real" (ASPR). A non-ASPR plant transfer function can be made ASPR using parallel feedforward configurations. Time derivative of $V(t)$ along the trajectories of Eqn. 32 can be obtained as,

$$\begin{aligned}\dot{V}(t) = \dot{e_x}^T Pe_x + e_x{}^T P\dot{e_x} + 2tr[\dot{K_{Ie}}(t)\Gamma_{Ie}^{-1}\big(K_{Ie}(t) - \tilde{K_e}\big)^T] \\ + 2tr[\dot{K_{Ix}}(t)\Gamma_{Ix}^{-1}\big(K_{Ix}(t) - \tilde{K_x}\big)^T] \\ + 2tr[\dot{K_{Iu}}(t)\Gamma_{Iu}^{-1}\big(K_{Iu}(t) - \tilde{K_u}\big)^T] \\ + 2tr[\dot{K_m}(t)\Gamma_m^{-1}\big(K_m(t) - \tilde{K_m}\big)^T] \quad (42)\end{aligned}$$

Replacing the value of $\dot{e_x}$, $\dot{K_{Ie}}$, $\dot{K_{Ix}}$, $\dot{K_{Iu}}$, in the above equation, we get

$$\begin{aligned}\dot{V}(t) \leq e_x^T\big(P(A_p - B_p\tilde{K}_eC_t) + (A_p - B_p\tilde{K}_eC_t)^TP\big)e_x \\ + 2e_x^TPB_p\big(\tilde{K}_e - K_e(t)\big)e_y - \sigma K_{Ie}^TK_{Ie} + \sigma\tilde{K_e}^TK_{Ie} \\ + 2e_x^TPB_p\big(\tilde{K}_x - K_x(t)\big)x_m + 2e_x^TPB_p\big(\tilde{K}_u - K_u(t)\big)u_m \\ + 2e_x^TPB_p\tilde{K_m}\Phi(x_p^*) - 2e_x^TPB_pK_m\Phi(x_p) \\ + 2e_x^TPB_p\Theta^T\big(\Phi(x_p^*) - \Phi(x_p)\big) - 2e_xP\zeta(t) \\ - 2e_y^T\big(\tilde{K}_e - K_{Ie}(t)\big)e_y - 2e_y^T\big(\tilde{K}_x - K_{Ix}(t)\big)x_m \\ - 2e_y^T\big(\tilde{K}_u - K_{Iu}(t)\big)u_m - 2e_{pre}^T\big(\tilde{K}_m - K_m(t)\big)\Phi(x_p) \\ (43)\end{aligned}$$

If the plant is made ASPR, then using (40) and (41), we can simplify the above equation as,

$$\begin{aligned}\dot{V}(t) \leq -e_x^TQe_x - 2e_y^TK_{pe}e_y - \sigma K_{Ie}^TK_{Ie} + \sigma\tilde{K_e}^TK_{Ie} \\ - 2e_y^TK_{px}x_m - 2e_y^TK_{pu}e_y + 2e_x^TPB_p\tilde{K_m}\Phi(x_p^*) \\ - 2e_x^TPB_pK_m\Phi(x_p) + 2e_x^TPB_p\Theta^T(\Phi(x_p^*) - \Phi(x_p)) \\ - 2e_xP\zeta(t) - 2e_{pre}^T(\tilde{K}_m - K_m(t))\Phi(x_p) \quad (44)\end{aligned}$$

We will assume that, during perfect tracking, $\tilde{K}_m = -\Theta^T$. Therefore,

$$\begin{aligned}\dot{V}(t) \leq -e_x^TQe_x - 2e_y^TK_{pe}e_y - \sigma K_{Ie}^TK_{Ie} + \sigma\tilde{K_e}^TK_{Ie} \\ - 2e_y^TK_{px}x_m - 2e_y^TK_{pu}e_y + 2e_x^TPB_p\big(\tilde{K_m} - K_m(t)\big)\Phi(x_p) \\ - 2e_xP\zeta(t) - 2e_{pre}^T\big(\tilde{K}_m - K_m(t)\big)\Phi(x_p) \quad (45)\end{aligned}$$

Considering, c_1, c_2, c_3, c_4, c_5 as positive constant, we can write the following,

$$-2e_y^TK_{pe}e_y = -2e_y^Te_ye_y^T\Gamma_{pe}e_y = -c_1 \parallel e_x \parallel^2 \leq 0 \quad (46)$$

$$-2e_y^TK_{px}x_m = -2e_y^Te_yx_m^T\Gamma_{px}x_m = -c_2 \parallel e_x \parallel^2 \leq 0 \quad (47)$$

$$-2e_y^TK_{pu}u_m = -2e_y^Te_yu_m^T\Gamma_{pu}u_m = -c_3 \parallel e_x \parallel^2 \leq 0 \quad (48)$$

$$\Phi(x_p) \leq c_4 + c_5 \parallel e_x \parallel . \quad (49)$$

$$-e_xP\zeta(t) \leq - \parallel e_x \parallel \lambda_{\min}(P) \parallel \zeta(t) \parallel \quad (50)$$

Therefore,

$$\begin{aligned}\dot{V}(t) \leq -\lambda_{min}(Q) \parallel e_x \parallel^2 - c_1 \parallel e_x \parallel^2 - \sigma K_{Ie}^TK_{Ie} + \sigma\tilde{K_e}^TK_{Ie} \\ - c_2 \parallel e_x \parallel^2 - c_3 \parallel e_x \parallel^2 \\ + 2 \parallel e_x \parallel \lambda_{min}(P) \parallel B_p\big(\tilde{K_m} - K_m(t)\big)\Phi(x_p) \parallel \\ - 2 \parallel e_x \parallel \lambda_{\min}(P) \parallel \zeta(t) \parallel \\ + 2 \parallel e_{pre} \parallel \big(-\tilde{K}_m + K_m(t)\big)(c_4 + c_5 \parallel e_x \parallel) \quad (51)\end{aligned}$$

Equivalently we can write,

$$\dot{V} \leq -K_1 \parallel e_x \parallel^2 + K_2 \parallel e_x \parallel + K_3 \quad (52)$$

where,

$$K_1 = \lambda_{min}(Q) + c_1 + c_2 + c_3 \quad (53)$$

$$\begin{aligned}K_2 = 2\lambda_{min}(P) \parallel B_p(\tilde{K_m} - K_m)\Phi(x_p) \parallel \\ + 2\lambda_{min}(P) \parallel \zeta(t) \parallel + \parallel e_{pre} \parallel c_5c_6 \quad (54)\end{aligned}$$

$$K_3 = 2 \parallel e_{pre} \parallel c_4c_6 - \sigma K_{Ie}^TK_{Ie} + \sigma\tilde{K_e}^TK_{Ie} \quad (55)$$

where, $c_6 = \max \parallel K_m(t) - \Theta \parallel$.
Therefore, $\dot{V}(t) < 0$ outside the compact set S_0

$$S_0 := \left(\parallel e_x \parallel \leq \frac{\frac{K_2}{K_1} + \sqrt{(\frac{K_2}{K_1})^2 + 4(\frac{K_3}{K_1})}}{2} \right) \quad (56)$$

Therefore, all signals of the error dynamics will remain uniformly ultimately bounded outside this compact set.

VI. SIMULATION

In this section, the proposed composite adaptive control in the presence of bounded disturbance is validated using the boost converter plant. The controller's objective is to track the desired output voltage. The plant states, control, and output variable, and tracking outputs are as follows: $x_p = [i_L, v_c]$; $u_p = d$; $y_p = [i_L, v_c]$; $y_t = v_c$. Here, the dimension of the output tracking variable and control input is the same, and the dimension of the output variable is more than the plant input. The circuit parameters are shown in Table I. The input voltage source is considered as 15 V, and desired output voltage is 30 V.

TABLE I: Important parameters

Parameters	**Value**
Voltage source (V_i)	15 V
Desired output voltage (V_c)	30 V
Inductor's resistance (R)	1 Ω
Inductor's nominal inductance (L)	1 mH
Capacitor (C)	1 mF
Nominal load resistance (R_L)	60 Ω

Using equation (5) and (6), the state matrix, control matrix and output matrix is obtained as follows.

$$A_p = \begin{bmatrix} -1000 & -464.1 \\ 464.1 & -16.7 \end{bmatrix}$$

$$B_p = [30000, -1077]'$$

$$C_t = [0, 1] \quad C_p = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

The pair (A_p, B_p) is controllable and the pair (A_p, C_p) is observable. The following reference model is considered in the simulation. It is to be noted that the output of reference model, that is y_m, is same as the dimension of tracking output (y_t).

$$\dot{x}_m = -200x_m + 200u_m \tag{57}$$

$$y_m = x_m \tag{58}$$

Matched state dependent uncertainty is considered as follows,

$$f(x_p) = \Theta^T \Phi(x_p) = k_1 i_L + k_2 v_c \tag{59}$$

where the value of k_1 and k_2 are considered as -0.001 and -0.002. The noise for the state i_L is considered as uniform noise in between 0 A to 0.1 A; whereas, the noise for the state v_c is considered as uniform noise in between 0 to 3 V. The plant is augmented with the suitable parallel feedforward configurations to make it ASPR. Simulation is performed in MATLAB using ODE-45 integration routine.

A. Results

The tracking of desired output voltage (V_c) of 30 V by the plant (v_c) and reference model (V_r) is shown in Fig. 2. The (V_r) represents the state x_m of the reference model. The plant is able to achieve the desired output voltage even in the presence of disturbances and state-dependent matched uncertainties. The variation of control input, that is, the duty ratio, is shown in Fig. 3 and the control input remains bounded during the simulation. The corresponding variation of controller gains (K_e, K_x, K_u, K_m) are shown in Fig. 4, Fig. 5 and Fig. 6. Variation of e_y and e_{pre} is shown in Fig. 7. It can be concluded that the overall plant remains stable while tracking the desired output voltage. The performance of the plant is checked for certain variations of R_L and input voltage V_i. Let be value of R_L is changed to 30 Ω from initial value of 60 Ω in between t= 0.25 sec to t=0.35 sec. The other simulation parameters, disturbances, are kept the same. The tracking of the desired output voltage by the plant is shown in Fig. 8a. The change in the drop of v_c at the instant of 0.25 sec is very small, and the plant is able to track the desired output voltage of 30 V quickly. The corresponding variation variation of duty ratio is shown in Fig. 8b. In the second experiment, the input voltage V_i is changed to 12 V from the initial value of 15 V at t=0.3 sec. The tracking of desired output voltage and variation of duty ratio is shown in Fig. 9a and Fig. 9b respectively. Clearly, the plant is able to track the desired output voltage of 30 V with small fluctuation.

VII. Conclusions

In this paper, we have applied the composite adaptive control framework to improve the efficiency of the boost converter in the presence of uncertainties in plant parameters and time-varying disturbances. Initially, the controller stability is analyzed in the presence of bounded disturbances, and then

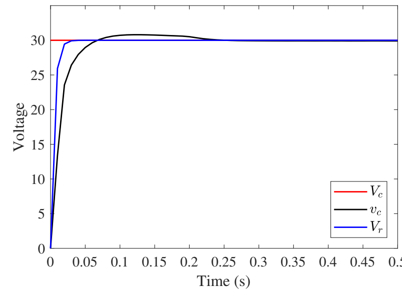


Fig. 2: Tracking of desired output voltage (V_c)

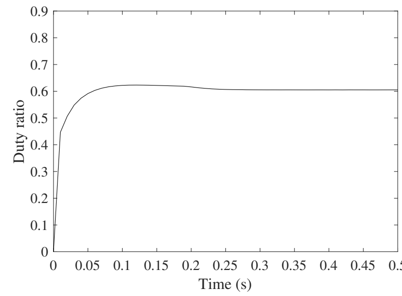


Fig. 3: Control input (d)

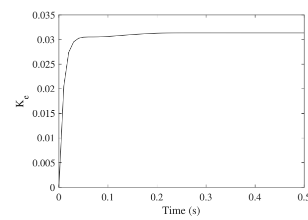
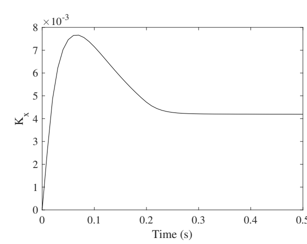
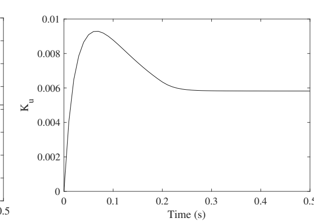


Fig. 4: Variation of K_e

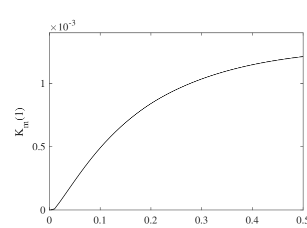


(a) Variation of K_x

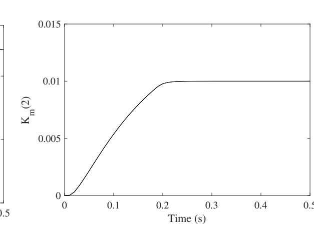


(b) Variation of K_u

Fig. 5: Variation of controller parameter

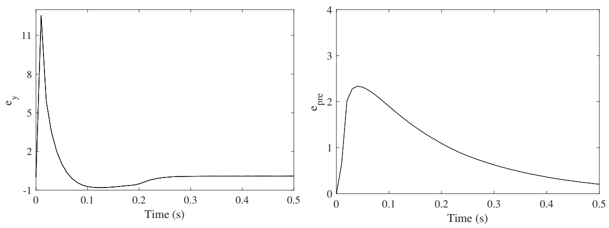


(a) Variation of $K_m(1)$



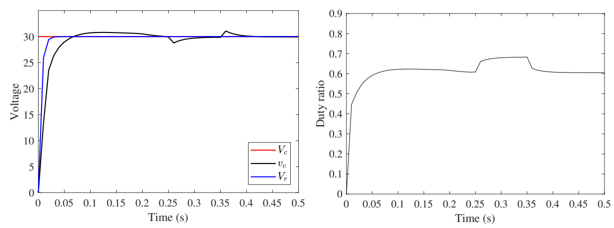
(b) Variation of $K_m(2)$

Fig. 6: Variation of K_m



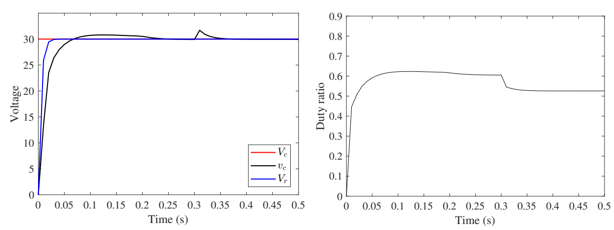
(a) Variation of e_y (b) Variation of e_{pre}

Fig. 7: Variation of tracking error and prediction error



(a) Tracking of V_c (b) Control input (d)

Fig. 8: Output voltage tracking and duty ratio for variation in R_L



(a) Tracking of V_c (b) Control input (d)

Fig. 9: Output voltage tracking and duty ratio for variation in input voltage (V_i)

the overall architecture is validated using the simulation of a boost converter. Simulation results show that plant is able to track the desired voltage, and the state/controller parameters remain bounded. The plant is also able to handle the sudden variation of load and input voltage.

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